Biophysical Interdisciplinary Trophic Studies (BITS)

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LONG-TERM GOAL

The long-term goal of our joint research program is the development of data-based models to predict ecological relationships of plants and animals to the physical and chemical environment in the sea.

OBJECTIVES

Understanding the marine ecosystem is limited by man's inability to observe life in the sea on scales in time and space that most directly impact individual animals. In lieu of having the ability to make direct observations of the animals and their environment, much of our knowledge about how they reproduce, live and die is inferential. Our thesis has been that improving the ability of the scientific community to detect and observe marine animals at any trophic level, especially in relation to the defining structure and characteristics of the food and physical environment, would improve the chances that we can understand and model the processes that control spatial distribution and temporal variability in marine ecosystems.

Our immediate objective was to provide a small number of new acoustical tools for studying zooplankton and micronekton, which scientists could afford and access. In addition to new sensors, we recognized that new methods of deployment for sensors of this kind were needed and effort was directed to developing those methods.

APPROACH

This project, now completed, was a joint University - Industry research program which involved scientists at Tracor and the University of Southern California. Funding for Tracor was provided by the Office of Naval Research and the National Science Foundation. USC's funding, including ship time for the project, was from the National Science Foundation. Tracor supplied the technology needed to develop new sensors and methods of deployment for the assessment of zooplankton and micronekton. USC provided the expertise and gear needed to deploy the moored systems, to conduct ground-truth experiments, identify the zooplankton and micronekton, and to measure the phytoplankton and the physical environment. Both groups participated in the analyses and publication processes for papers and presentations dealing both with technology development and with observations describing the relationships between the biota and its physio-chemical environment.

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In our research, we focused on using our knowledge of the details of the scattering from small zooplankton and micronekton to design relatively simple, ”user-friendly” instrumentation for studying zooplankton spatial distributions and temporal variability in abundance. We wanted to develop sensors that did not require an ”expert” presence for maintenance and operation, or a specialist to interpret the results. The constraints on cost, ease of use, deployment method and the final accuracy with which one can estimate zooplankton size and abundance can vary with the science problem one is working. Thus, an instrument that is optimal for one use is not necessarily optimal for others. Forcing a single implementation to address all of the possible science problems in biological oceanography would have resulted in a tool that would have been much more complex, and costly to maintain and use, than was practical. Early recognition of this fact encouraged us to focus on the development of a small number of relatively easy to use tools rather than on developing a single, all encompassing, complex tool.

As we developed new methods for deployment and simpler sensors, e.g., systems that use only one, two, four, six and eight discrete frequencies, we applied those advances to examine a variety of ocean ecosystems during cruises in several different marine environments. While evaluating the different concepts and sensors we developed, we also used those systems at both oceanic and coastal sites; collecting and interpreting the data with the objective of understanding the interrelations of phytoplankton, zooplankton, the benthos, and their collective physical environments.

The principles of multi-frequency acoustics date to work by McNaught (1969), but were largely made quantitative in the 1970s (e.g., see Holliday 1972; Holliday, 1977a; Holliday, 1977b; Greenlaw, 1979; and Greenlaw and Johnson, 1983). A concise summary of the scientific principles behind the multi-frequency acoustics, which includes the reasons that single frequency acoustics can be misleading when applied to the assessment of zooplankton and micronekton, can be found in Holliday (1972) and in Holliday and Pieper (1995).

The primary focus of our work, especially within the context of this project, was on zooplankton and micronekton, but we have also applied our technology to swimbladder bearing nekton to detect benthic animals and those that move between the seabed and the water column, i.e., the bentho-pelagic community. For small crustaceans in the water column, our sensors measure the distribution of biomass, by size, between tens of microns and centimeters. These sensors are used on moorings, are lowered from or towed by ships, and have also been deployed as inverted echo sounders in shallow water. The data collected are used to: a) observe and understand the relationships between primary and secondary producers; and b) to observe distributions of the animals in relation to their food and physical environment. We continue to train biological oceanographers who wish to use multiple high frequencies of sound as a tool in their own research, providing access to the most advanced multi-frequency acoustical sensors and software with which they can convert acoustical measurements of volume scattering strengths to biomass-size spectra, thereby shortening their "learning curves”.

Based on our previous experience with the MAPS, we defined a small suite of acoustical instruments for studying the spatial and temporal relationships of small zooplankton and micronekton and the physics of the oceanographic environment. During this research project, in response to the needs of several different kinds of science programs, we evolved three distinctly different kinds of instruments, each of which employed multiple signal processing algorithms. They were: 1) a very simple, energy efficient bi-frequency sensor, to be used primarily at discrete depths on moorings, 2) several multi-frequency

sensors (four, six and eight frequencies), primarily to be used in a cast mode along with a CTD or to be towed in a package of instruments, e.g., on a SeaSoar vehicle or a MOCNESS, and 3) a very simple, low cost wideband system with the capability of attaining high spatial resolution, especially in the vertical dimension.

WORK COMPLETED

All of the work on this contract is now completed and a summary final report is available on request (Tracor Report No. T-98-56-0001-U). Seventeen peer-reviewed publications resulted from full or partial support under this contract. The final report and reprints of the related publications can be obtained by contacting “holliday@galileo.tracor.com”.

RESULTS

The detailed results of our BITS program of research are documented in seventeen peer-reviewed publications, seven manuscripts and technical reports, forty-one invited presentations and twenty-two papers contributed to scientific meetings over the term of the program. These contributions document both the technology and the science observations made during the research.

The methods we developed in the context of our ONR funded research are now described in textbooks and are commercially available to the next generation of acoustical oceanographers, fisheries biologists and biological oceanographers (e.g., MacLennan and Simmonds, 1992; Medwin and Clay, 1997).

IMPACT/APPLICATION

Understanding a marine ecosystem requires measurement of pattern (spatial distribution) and sensing of the processes happening within that pattern. Our technology addresses both issues for small zooplankton. Access to means for measuring and describing pattern in assemblages of zooplankton has become accessible to non-acoustician biologists in a quasi-synoptic form via our zooplankton acoustics sensor technology. Temporal estimates from our moored acoustics and repetitive occupation of fixed stations and transects are providing insight into the time scales and dynamics of the processes that result in and modify pattern.

TRANSITIONS

Our research under this contract was a cooperative program involving the University of Southern California and Tracor. At various times during this project, project personnel work to transfer the technology to scientists and engineers at the University of Washington (Oceanography), University of Washington / APL, the University of Rhode Island, Oregon State University, the University of California at Santa Barbara, the Wildlife and Fisheries Department of the State of South Carolina, NOAA / NMFS Auke Bay, NOAA / AOML, NOAA / NMFS Sand Point, NOAA / NMFS Narragansett, WHOI, NRL Stennis, NRL DC, SPAWAR San Diego and NCSL Panama City. In work on Georges Bank, we worked with PI's from the NSF GLOBEC NW Atlantic program. Work in the Arabian Sea was a cooperative project with PI's in the ONR ARI on Forced Upper Ocean Dynamics, the NSF US JGOFS program and NOAA / AOML. In several of these cooperative research efforts, the

bulk of the participation was funded via a separate vehicle from the agency or institution mentioned with critical, but minimal financial support from this ONR contract (often for data analysis and publication support). This technology development was jointly sponsored by the Office of Naval Research and the National Science Foundation. The funding for the engineering development, design and fabrication of the TAPS™ sensors, a commercial product, was from Tracor.

RELATED PROJECTS

Long-term data collection and monitoring on Georges Bank and in Narragansett Bay is continuing and is planned within the NOAA / NMFS lab at Narragansett, with a TAPS™ built for Drs. Mark Berman and Jack Green (NOAA / NMFS Narragansett, RI). Under separate (ONR DURIP) funding, we have built a TAPS-6™ for Drs. Sharon Smith and Harry DeFerrari (RSMAS, Univ. of Miami). We also upgraded an early version of the TAPS™ for Dr. Peter Ortner (AOML / NOAA). TAPS™ has also been used in ONR sponsored research on scattering from benthic assemblages in the San Juan Islands of WA. Observations of diel migrations from the benthos into the water column from this work are the subject of detailed investigation by one of Dr. Peter Jumars' graduate students at the University of Washington. A TAPS™ was used on a SeaSoar and on CTD casts in the ONR Arabian Sea project during several JGOFS cruises. The NSF-sponsored Land Margin Ecosystem Research program in the Chesapeake Bay and a NOAA Sea Grant study on the ingress of shrimp larvae from the sea into the Ogeechee estuary in Georgia are also TAPS™ users. ORSTOM (France) is using one of our TAPS™ in a program of research on the food web that supports the tuna population in the equatorial Atlantic (PICOLO). Two TAPS™ were used by NOAA / NMFS scientists at the NMFS Auke Bay Laboratory to study the food environment for salmon in the North Pacific. Another NMFS scientist has been using the TAPS™ for studies of food aggregation in relation to a series of quasi-permanent fronts in the Pribolof Islands of the Bering Sea. We have recently completed a project related to understanding the ambient (including bioacoustics) and shipping noise components in the context of the Navy's Full Spectrum program. A small part of this project involved working with project scientists at NRL/DC, NRL Stennis, UCSD/SIO/MPL and NRaD on coastal zone oceanography and bioacoustics (fish and marine mammals) in relation to ambient noise fields in the littoral zone near the site of the SWELLEX II and the SWELLEX III field experiments. Our contributions included advice and consulting on biological sources (snapping shrimp and croaker) of coastal zone ambient noise in the vicinity of the SWELLEX III experiment.

Funding for these investigations has usually been in small amounts, covering the lease cost for the TAPS (which in turn covers shipping and the maintenance and calibration of the instrument). These projects are independent of this ONR project, *but the availability of the technology used was a direct result of our ONR support*. Investigators at these institutions are using TAPS acoustical data and its derivative products (zooplankton abundance and distribution by size) to describe and analyze the plankton ecosystem in their own special areas of interest. We include this information here as additional evidence that the technology development sponsored by ONR has been successfully transitioned to a variety of different communities, in fulfillment of one of the objectives of this contract.

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